Fermilab

Main Injector HLRF ON/OFF and Track/Hold Gates Timing

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Abstract: *Each Main Injector high-level RF (HLRF) station uses an ON/OFF gate for abrupt gating of its RF drive. Before a station is gated OFF its cavity tuning drive signal is captured and held via a Track/Hold module. It is released upon abruptly turning the station back ON at the same frequency. This note documents the Track/Hold module timing and the necessary state transition timing for the HLRF station gates.*

Track & Hold Module Timing

The timing performance of the Triple Track & Hold module (0431.00-EC-180746) was measured by using two synchronized square wave generators; one to provide the HOLD gate and the other to provide a changing INPUT signal. When in the Track mode (HOLD trigger is low) the OUTPUT should follow the INPUT. When in the Hold mode (HOLD trigger is high) the OUTPUT should remain constant at the INPUT value that was present at the time of the HOLD trigger.

First the delay to go from a Hold to a Track mode was measured as shown in Figure 1. The INPUT was changed while the OUTPUT was in the Hold mode. The settling time (~2% error) is ~ 40 usec for the OUTPUT to return to tracking the INPUT.

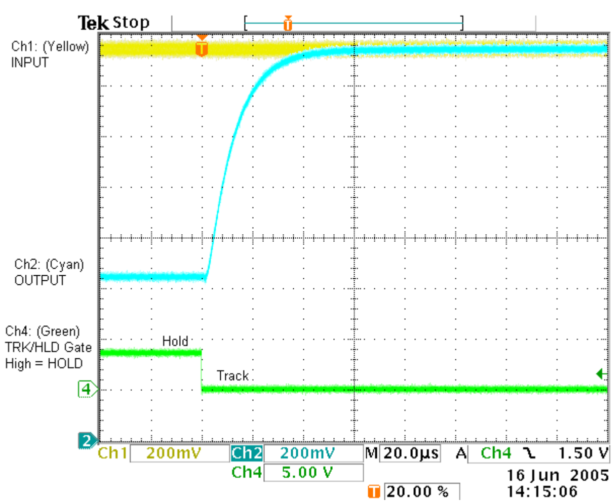

Figure 1: Hold to Track mode transition has a ~40 usec settling time.

The 40 usec settling time appears to be due to the natural bandwidth of the module in the Track mode and not due to the switching of the Sample and Hold process. This is evidenced in Figure 2 which also shows the OUTPUT response to a step transition during the Track mode.

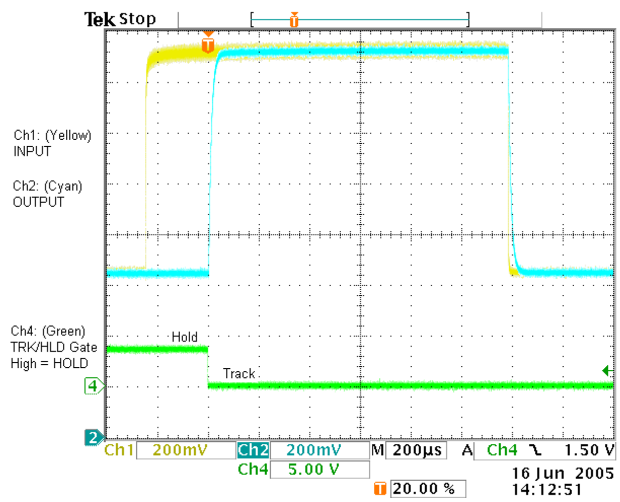

Figure 2: The natural step response in the Track Mode

The settling time of the transition from the Track mode to the Hold mode is much faster as evidenced in Figure 3. The INPUT can begin to change simultaneously with the HOLD gate transition.

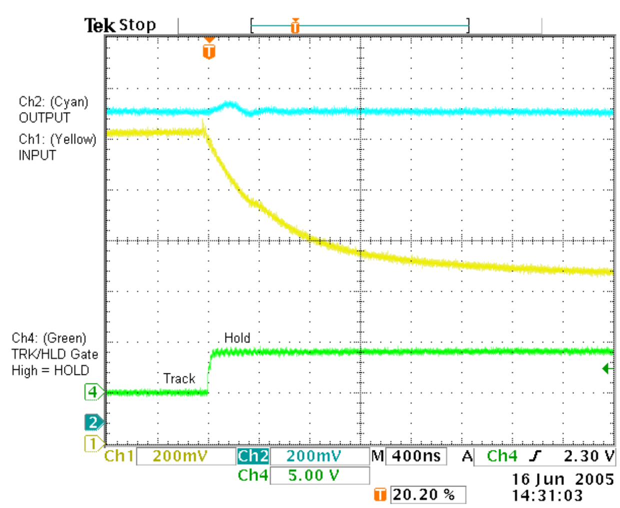

Figure 3: The Track to Hold transition.

The ringing in the OUTPUT which lasts ~800 nsec appears to be due to the Sample and Hold process. This is evidenced in Figure 4 which shows the same ringing even when the INPUT is held constant across the Track to Hold transition.

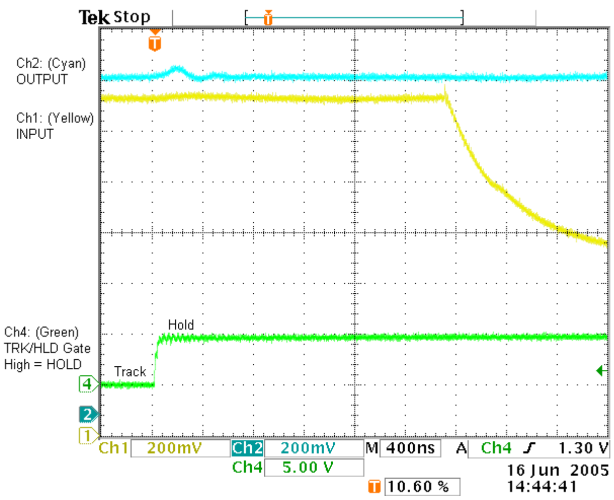

Figure 4: The ringing in the OUTPUT is due to the Sample and Hold process.

Furthermore, due to the natural step response of the module in the Track mode, the INPUT can actually begin to change before the Track to Hold mode transition with no appreciable error resulting in the value that is held and captured by the Sample and Hold process. This is evidenced in Figure 5.

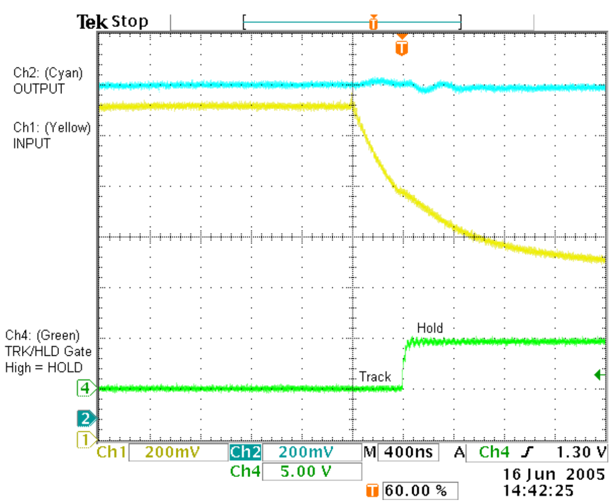

Figure 5: Response to an INPUT change before the Hold

HLRF Station Gates Transition Timing

For this discussion there are two primary states of operation for a HLRF station: a (On,Track) state and a (Off,Hold) state. The (On,Track) state means that the station is on and producing RF gap voltage while the cavity tuning loop is on and tracking its appropriate control signal. The (Off,Hold) state means that the station's RF Drive has been gated off and its cavity tuning control signal is being held. The latter state gates off only the RF Drive, not the Direct RF feedback nor the RF Feed-Forward drive signals. It is used when one wants to make zero cavity volts while keeping both the beam loading compensation loops active and the cavity at a specifically held tune value.

The HLRF station state is controlled via two gates: the ON/OFF gate and the Track/Hold gate. A state transition between (On,Track) to (Off,Hold) and vice versa can include going through the intermediate state (On,Hold). The (Off,Track) state is not of particular use at this time and will not be considered here.

From the previously presented measurements, the Track & Hold module should support an immediate transition from (On,Track) to (Off,Hold) without having to use the intermediate state. However, for the (Off,Hold) to (On,Track) state transition, the (On,Hold) intermediate state is useful for allowing the station to turn back on and settle before releasing the Track/Hold to allow the cavity tuning loop to begin tracking again. The timing between these transitions is investigated and documented in the following.

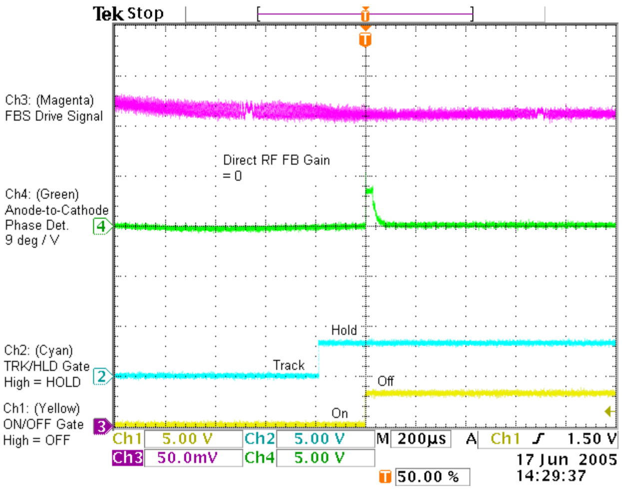

Figure 6: (On,Track) to (Off,Hold) delay=200 usec

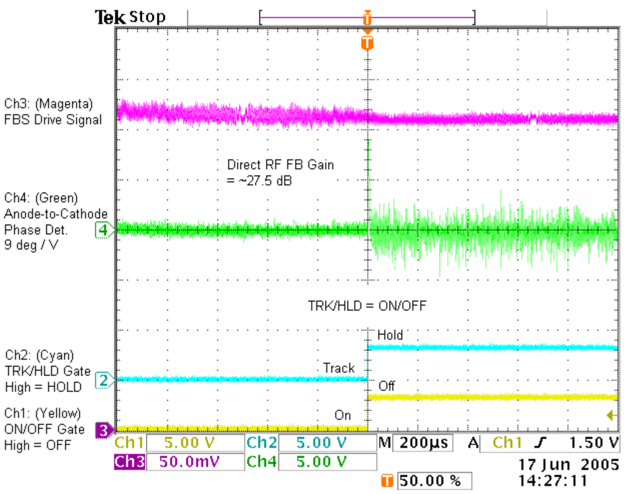

Figure 7: (On,Track) to (Off,Hold) delay = 0 with Direct RF Feedback Gain = 27.5dB

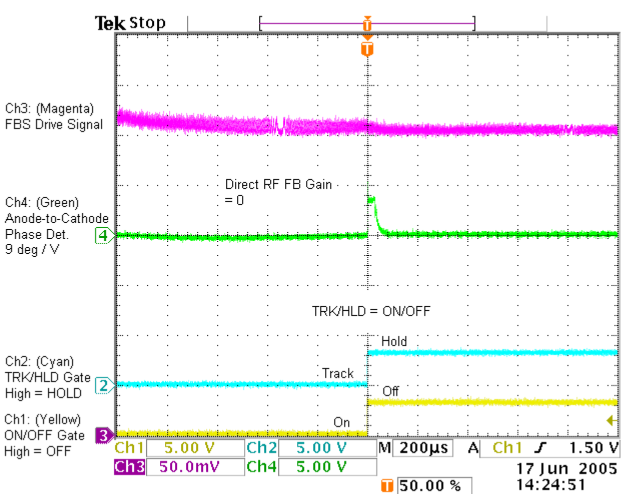

Figure 8: (On,Track) to (Off,Hold) delay = 0 with Direct RF Feedback Gain = 0 (off)

(On,Track) to (Off,Hold) Transition

Proof that an immediate (zero delay) transition from a (Track,On) to a (Hold,Off) state can be implemented is shown in Figures 6-8.

Figure 6 shows the response of the cavity tuning feedback loop parameters when the delay between the (On,Track) to (Off,Hold) is ~200 usec. Figures 7 and 8 show the response with zero delay between the states (the Track/Hold gate is made equal to the ON/OFF gate) with and without Direct RF FB respectively. The only difference in the Ferrite Bias Supply (FBS) drive signal (cavity tuning setpoint) between figures 7 and 8 is a few millivolts. However, this is NOT due to the gating; it is due to the drift in the cavity tuning that occurred between plot captures.

The Track/Hold gate can be made equal to the ON/OFF. There is no noticeable change in acquiring the proper hold-value with or without a delay between (On,Track) to (Off,Hold) nor with or without Direct RF FB. There is no change in the Anode-to-Cathode phase detector output between using a delay and not using a delay when Direct RF FB is off. The difference in the Anode-to-Cathode phase detector output with Direct RF FB on is due to the cavity being driven down faster upon turn-off and the noise during the (Off,Hold) state. This noise may be due to noise injected into the cavity by the Direct RF FB loop which is still active during the (Off,Hold) state.

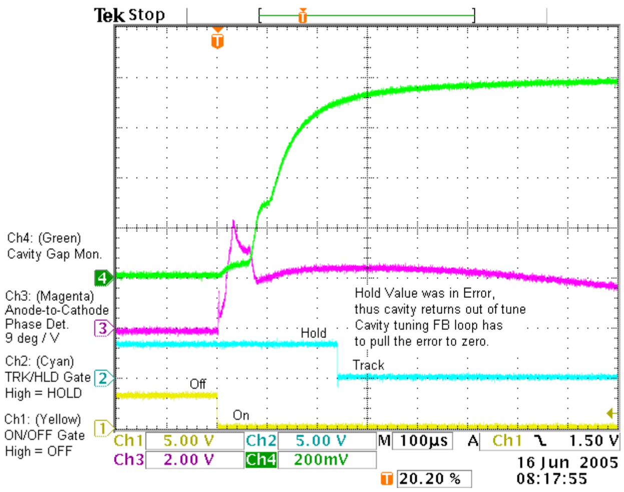

Figure 9: (Off,Hold) to (On,Track) delay =~ 200usec

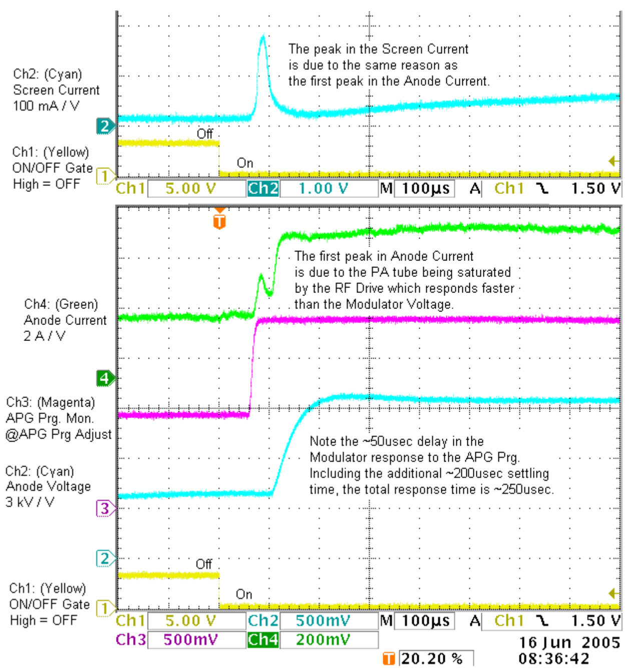

Figure 10: (Off,Hold) to (On,Track) delay =~ 200usec

(Off,Hold) to (On,Track) Transition

A delay is needed when transitioning in the (Off,Hold) to (On,Track) direction. This delay allows the station to first turn on (On,Hold) and the cavity voltage to settle before releasing the Track/Hold gate. This is evidenced in figures 9 and 10. The ~200 usec delay includes allowance for the anode-to-cathode phase (the cavity tuning loop error signal), the cavity voltage, and the modulator voltage to settle. Note that the modulator output voltage has a long settling time of ~250usec, 50usec of which is pure delay from the APG (anode program) to the modulator beginning to respond.

Note that the cavity tune (anode-to-cathode phase) initially comes up in error. Noise in the ferrite bias supply (FBS) drive signal makes it very difficult to capture the average tuning value before the station is turned off (see figure 11). Thus there will always be some tuning error that the cavity tuning loop has to correct upon the station turning back on and releasing the Track/Hold gate. The cavity tuning loop settling time is ~6msec. The cavity gap voltage settling time is faster due to the Direct RF FB loop.

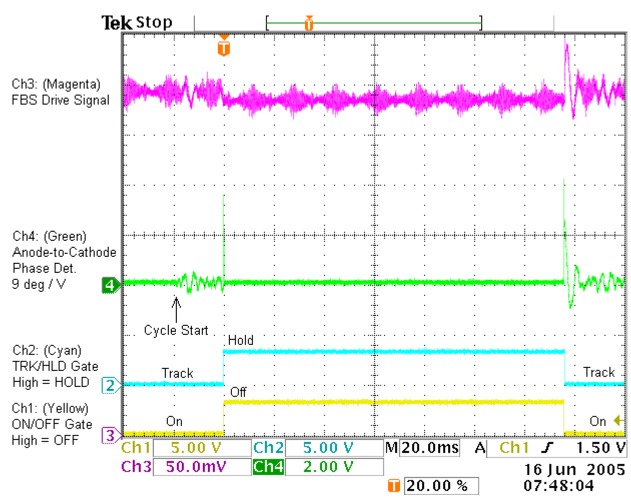

Figure 11: Noise in the FBS Drive Signal makes it difficult to capture the average tuning value.

Conclusion

The recommended transition delays are 0 usec for a (On,Track) to a (Off,Hold) transition. For the reverse direction, (Off,Hold) to (On,Track), a 250 usec delay is recommended even though the delay used in this paper was slightly lower. The MRF VXI system has incorporated these recommendations.